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STUDIES ON ZOOPLANKTON BIOMASS AND SECONDARY AND TERTIARY PRODUCTION OF THE EEZ OF INDIA

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ABSTRACT

The zooplankton collected from 1,113 stations occupied in the EEZ of India and contiguous seas during the cruises 1-44 of FORV *Sagar Sampada* during 1985-'88 has been analysed for spatial distribution, monthly and seasonal abundance and diurnal variations. The data obtained have been used for estimating the biomass and secondary production on a half degree square basis and fish production for every one degree square in the EEZ.

In general it has been found that the waters off the west coast were more productive. Pockets of very high density of over 1,000 cc of zooplankton per 1,000 m^3 of water were observed off Cochin and Mangalore. Fairly high density areas were frequently encountered all along the shelf area off the west coast especially the Wadge Bank area, the Gulf of Mannar, off Cochin, Mangalore, Goa and along the Gujarat coast. In the oceanic area of the eastern Arabian Sea also high desity areas were frequently met with. Off the east coast, high density areas were noticed north of Mardas and off Kakinada. East of Andamans and around Nicobar Island, there were restricted areas of zooplankton abundance.

The average density of zooplankton in the entire area investigated has been estimated to be 88.33 cc per 1000m^3 of water. The average zooplankton biomass in the entire shelf area of both the coasts of India and the Andaman and Nicobar Islands has been estimated to be 164.04 cc against a biomass value of 54.75 cc for the entire oceanic areas. A consideration of the biomass in the shelf and oceanic areas separately for the two coasts showed that the shelf area of the west coast with 200.25 cc accounted for the maximum followed by the shelf area of the east coast including the Andaman and Nicobar Islands with only 92.25 cc. In the oceanic area also the biomass almost doubled in the eastern Arabian Sea (67.66 cc) than in the Bay of Bengal (36.65 cc). A further estimate of the biomass during the three seasons indicated that in the shelf area the average values for the premonsoon, monsoon and postmonsoon were 101.05, 216.85 and 132.51 c c respectively. The same in the oceanic areas was found to be 45.03, 72.89 and 49.37 cc respectively thus indicating a two fold increase in the shelf region during the pre and postmonsoons and a three fold increase during the monsoon season. While the day samples yielded a quantity of 83.44 cc, the night samples made up 95.99 cc.

A half degree wise production at the secondary level was worked out and it was found that the values ranged between 0.5 and 20.92 $gC/m^2/year$. From the values of secondary production, the fish production was worked out for the total area under study and for the EEZ. Accordingly it was seen that the fish production in the Indian EEZ could be 7.46 million tonnes with split values of 4.78 mt for the west coast, 1.32 mt for the east coast and 1.37 mt for the Andaman and Nicobar Seas.

INTRODUCTION

The history of zooplankton investigation in the Indian Ocean dates back to 1857 when the ship *Novara* engaged 52 stations along 40°S eastward upto 80°E meridian, along 85° E meridian northwards upto Madras and eastward upto Sumatra. Afterwards several expeditions have visited some or the other parts of the Indian Ocean and made plankton sampling. However, these collections were mainly used for faunistic studies. The first major attempt to study the quantiative distribution and abundance of zooplankton of the Indian Ocean was by the International Indian Ocean Expedition (1960-'65) during which ships of several countries participated. Eventhough the studies gave a general picture about the quantitative distribution and abundance of zooplankton (Prasad, 1968, 1969; Rao, 1973), due to inadequacy of samples the results obtained were not very conclusive. Nor was it possible to make any seasonal studies. Except for a few locations, especially in the northern parts of the Indian Ocean, the number of samples available for a 5° area was less than 10.

Apart from the IIOE, many other intensive but localised surveys for zooplankton have been carried out subsequently. RV *Varuna* investigated the shelf and oceanic waters of the southwest coast of India (Ramamirtham and David Raj, 1981); RV *Rastrelliger* and RV *Sardinella* of the erst-while Pelagic Fisheries Project, Government of India made detailed but restricted studies in the shelf waters between Ratnagiri and Tuticorin (Anon., 1973, 1976;

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Menon and George, 1977). Recently the National Institute of Oceanography has come out with an Atlas (Supria *et al.*, 1988) which gives the zooplankton biomass of the EEZ based on a mere 464 samples collected during 1976-'80 by RV *Gaveshini*.

All the above studies point to the inadequacy of coverage or insufficiency of samples for arriving at proper conclusions with regard to distribution and abundance of zooplankton in space and time. In view of this, an attempt is made here to study the total zooplankton biomass and the secondary production of the eastern Arabian Sea, the Bay of Bengal and the Andaman & Nicobar Seas. Using the secondary production data obtained during the present studies an attempt has also been made to work out the tertiary production in the area investigated. The present study is one step ahead of the earlier investigations rather than a continuation, for the reason that the areas covered are far wider and the frequency of sampling much better.

Material and Methods

The material which formed the basis of the study was collected onboard FORV *Sagar Sampada* from the Indian EEZ and contiguous seas during the period 1985-'88. The gear used was Bongo -60 net with a mesh size of 0.33 mm. Hauls were made from 150 m to surface in oblique manner with the ship in motion at 2 knots speed. A precaliberated flow meter was used in most cases and hence the data on biomass as well as individual zooplankton groups could be quantified. The plankton was preserved in 5% formaldehyde solution. In the laboratory the total volume was determined by displacement method. After removing the macroplankton, a minimum of 5 cc of zooplankton was sorted out into different groups and enumerated. The biomass as well as individual groups were estimated for 1000 m^3 of water.

For the purpose of comparisons, the area under investigation was divided into four latitudinal regions namely, Region-1: 04°30'N to 10°N; Region-2 : 10°N to 15°N; Region-3: 15°N to 20°N, region-4 : 20°N to 23°N. The area west of 77°30'E was considered as eastern Arabian Sea and that east of it as Bay of Bengal. The shelf area mentioned in the paper is the area within the continental shelf and that beyond it is called as oceanic area. The three seasons recognized in the paper are premonsoon from February to May, monsoon from June to September and postmonsoon from October to January. The samples collected between 0600 and 1800 hrs have been considered as day samples and those collected between 1800 and 0600 hrs as night samples. A total of 1113 zooplankton samples colected during cruises 1-44 have been analysed for the present study. For obtaining finer details of quantitative distribution in space, biomass values have been worked out for every half-degree square area against 5° square followed for the IIOE data. For this purpose the number of stations occupied in each half-degree square were considered together and the data obtained were pooled together. The estimates for secondary and tertiary production were made following the method by Cushing (1973) and later modified by Dalal and Parulekar (1986). All the data were analysed in a computer.

Results and Discussion

Coverage and frequency of sampling

Figure 1 Shows the area covered by the *Sagar Sampada* for zooplankton sampling and the frequency of sampling in each half degree square. Off both the coasts and the Andaman and Nicobar seas, sampling was not strictly confined to the EEZ but the neighbouring areas were also covered. This was especially so in the case of Bay of Bengal which was almost entirely covered though less intensively. The coverage was more intensive off the southwest coast. However, adequate sampling has been done in other areas also including the Andaman and Nicobar seas. Incidently it is to be mentioned that this is the first time a study is made on zooplakton of the Indain EEZ making use of such enormous data.

Spatial distribution

For drawing the isolines of biomass density in space, the values were broadly categorised into five to represent the ranges between 1 cc and more than 500 cc per 1000 m^3 of water. The results obtained are depicted in Fig. 2. In general the waters off the west coast was more productive. There itself the shelf area was highly productive. Pockets of very high density of zooplankton were observed off Cochin (1,228.32 cc/ 1000 m^3 at 09°00'N 76°19'E) and off Mangalore (1,968. 25 and 1,527.51 cc/1000m^3 at 10° 30'N 75° 40' E and 10°30'N 75° 30'E respectively). High-density areas were rather frequently encountered all along the shelf off the west coast especially in the Wadge Bank area, the Gulf of Mannar, off Cochin, Mangalore, Goa and along the Gujarat coast (Fig. 2). In the oceanic waters also

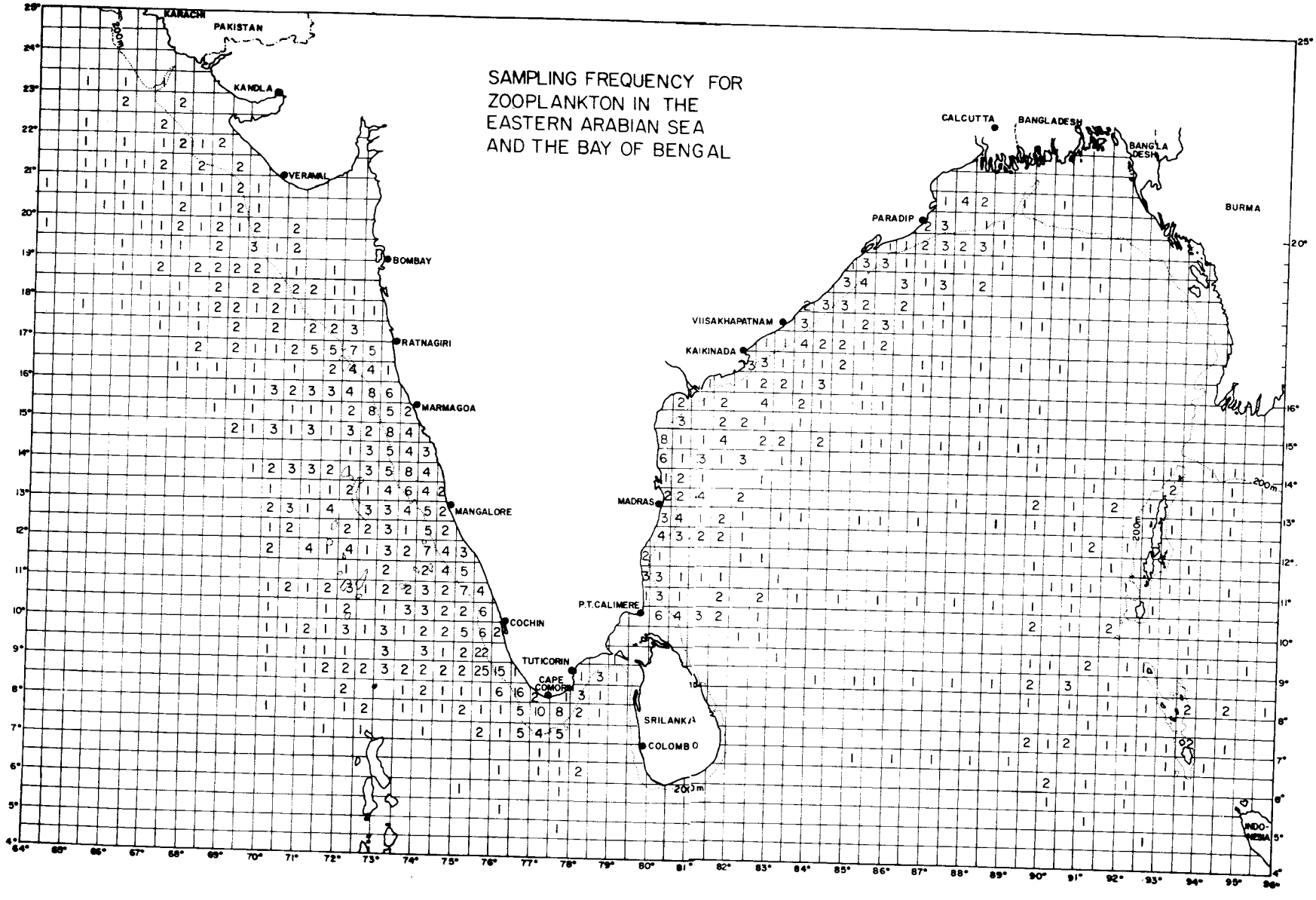

Fig. 1. Sampling frequency for zooplankton in each half degree square.

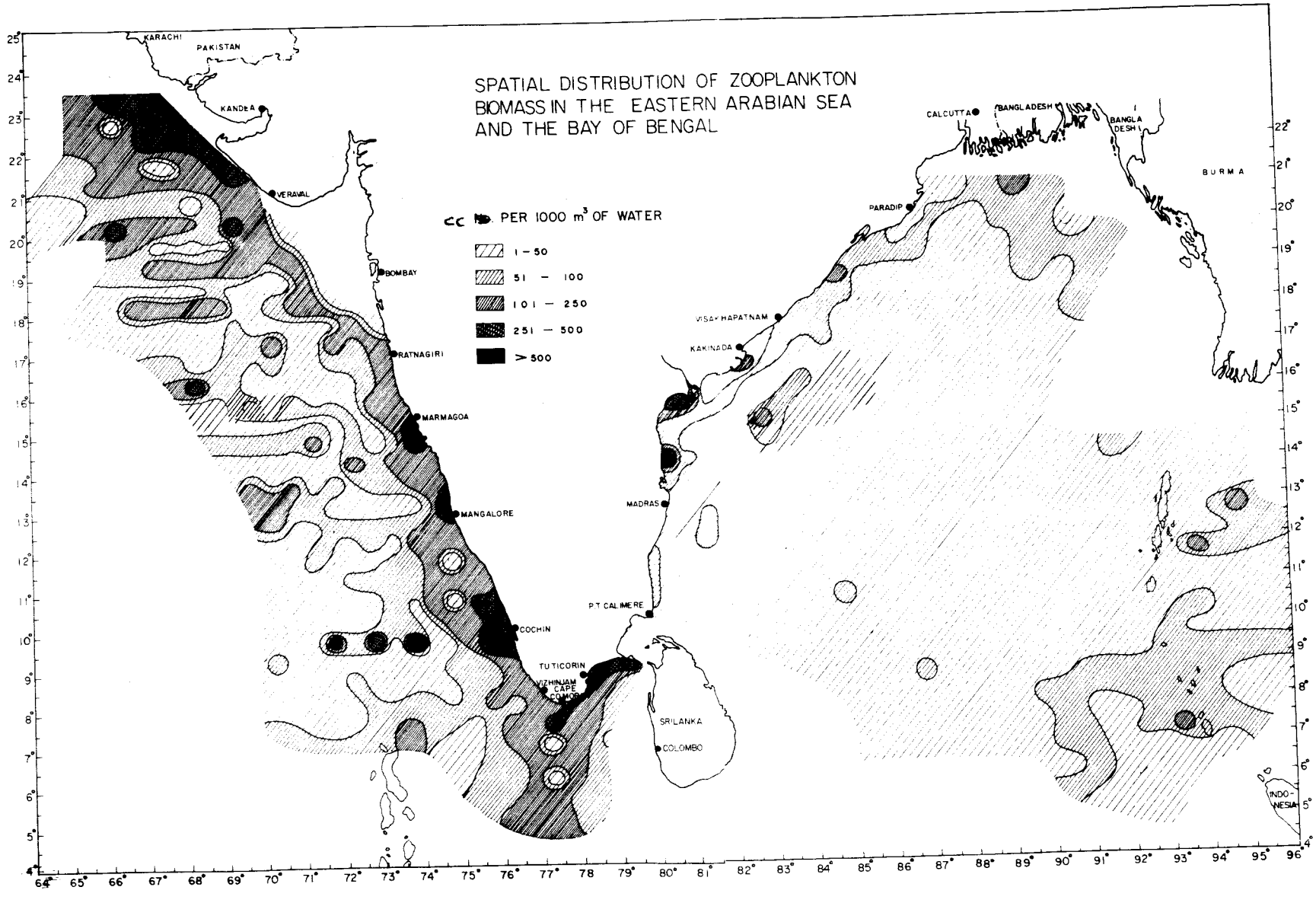

Fig. 2. Spatial distribution of zooplankton biomass.

high-density areas were frequently met with in the eastern Arabian Sea. In a recent atlas made for the zooplankton of the EEZ of India, Supria *et al.* (1988) have shown highly productive areas off Veraval, Bombay , Goa, Mangalore and Kanyakumari, and this is in conformity with the present investigations.

The zooplankton biomass was rather sparse in the Bay of Bengal, where in the oceanic waters, the density was below 50 cc/1000 m^3. However , around Nicobar Islands the production ranged between 51 and 100 cc. East of Andaman also there were restricted areas of abundance. In the shelf waters off the east coast the rate of zooplankton production was relatively better than in the oceanic area. Localised high-density areas were noticed north of Madras and off Kakinada. On the whole, moderate to low production appears to be the general trend in the shelf area of the east coast.

The biomass values obtained for the EEZ and the neighbouring waters have made it possible to work out some generalised figures for the overall average density of zooplankton for the different water areas on a broader basis. Thus the average density of zooplankton in the entire area has been estimated to be 88.33 c c per 1000 $m^3$of water. The area was further divided into shelf and oceanic areas and the average values obtained for the respective areas were 164.04 and 54.75 cc per 1000 m^3 of water which indicated that the shelf waters were three-times more productive. A consideration of the biomass in the shelf and oceanic regions separately for the two coasts showed that the shelf area of the west coast with 200.25 cc was the maximum productive, followed by the shelf area of the east coast with only 92.25 cc. In the oceanic area also the biomass of the west coast (67.66 cc), was almost double than that of the east coast (36.65 cc).

A further estimate of the biomass during the three seasons indicated that in the shelf area the average values for premonsoon, monsoon and postmonsoon were 101.05, 216.85 and 132.51 cc respectively. The same in the oceanic areas were found to be 45.03, 72.89 and 49.37 cc respectively. While the average density of zooplankton during day time was 83.44 cc the same in the night was 95.99 cc.

Monthly variation in abundance

Figure 3 shows the monthly variation of plankton in the study area. The general trend observed was that the period from June to December was highly productive with the maximum during August when the average monthly biomass reached 182 cc per 1000 m^3 of water. This was followed by September during which month the average value obtained was 116.70 cc. The least value of 28.72 cc was obtained in May. The monthly values when categorised into three seasons, it was found that the monsoon season (June-September) accounted for the maximum biomass of 121.96 cc followed by the postmonsoon season (October - January) with 77.63 cc and the premonsoon (February-May) with the least value of 54.405 cc. Rao (1973) who worked on the Indian Ocean zooplankton also found the July-September period to be the maximum productive season.

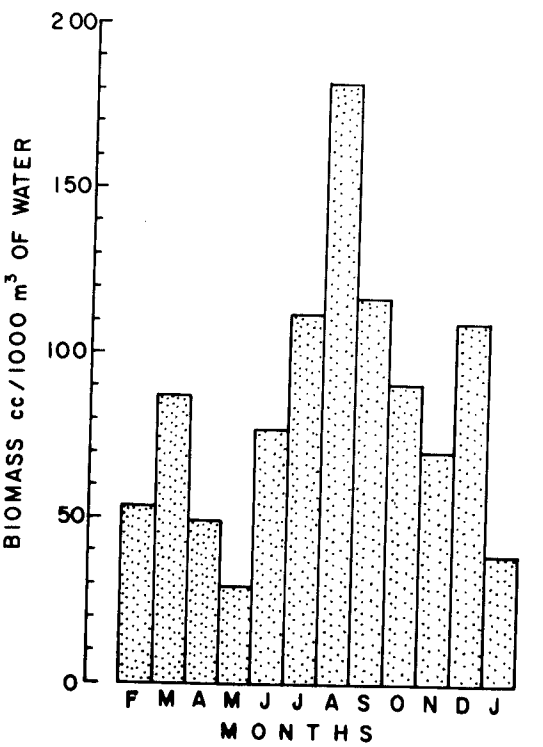

Fig. 3. Monthly abundace of zooplankton biomass in the area studied.

A further attempt was made to understand the variations in monthly abundance in the eastern Arabian Sea and the Bay of Bengal separately (Fig. 4). On the whole about 60 to 80% of the plankton was obtained from the west coast. However, during January, February and April the biomass off the east coast was found to be relatively more than that off the west coast. Off the west coast, the maximum biomass value (average 133.00cc) was found from June to September followed by the October to December period (average 100. 02 cc).

Off the east coast the period of maximum production was from July to October (average 86.29 cc). The results obtained for the west coast is in agreement with the earlier findings for the whole Arabian Sea and for localised areas. Thus Prasad (1969) recorded the maximum production during the southwest monsoon. Same was the observation made by Menon and George (1977) and Ramamirtham and David Raj (1981) in the shelf waters of the southwest coast of India.

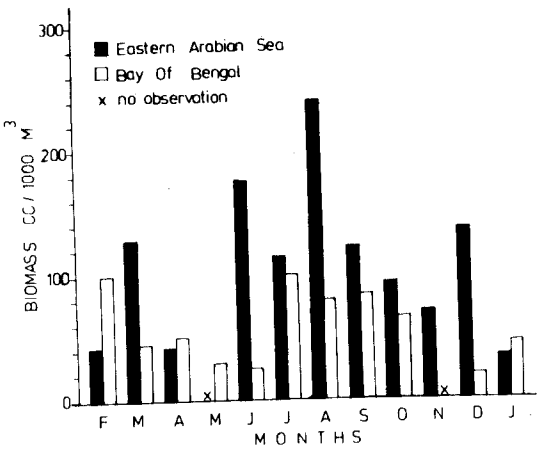

Fig. 4. Monthly abundance of zooplankton biomass in the eastern Arabian Sea and the Bay of Bengal.

A comparison between biomass values obtained for the shelf and oceanic areas for the total area investigated was made and the results are presented in Fig. 5. As could be expected the shelf was found to be far more productive than the oceanic areas and the increase was of the order of 60 to 80%. Regarding the month to month variation, it was found that in the shelf area while the period from June to October appeard to be very rich in plankton, in the oceanic area the corresponding period was from July to December.

Latitudinal abundance

The whole area investigated was divided into four latitudinal grids i.e., upto 10°N, 10-15°N, 15-20°N and above 20°N. In general it was found that in the eastern Arabian Sea, the zooplankton biomass gradually increased form south to north with the exception in the 3rd latitudinal region which recorded the maximum of 83 cc per 1000m^3 of water (Fig. 6). In the Bay of Bengal, on the other hand, region-1 (southernmost) was the maximum productive which itself was less than the least productive

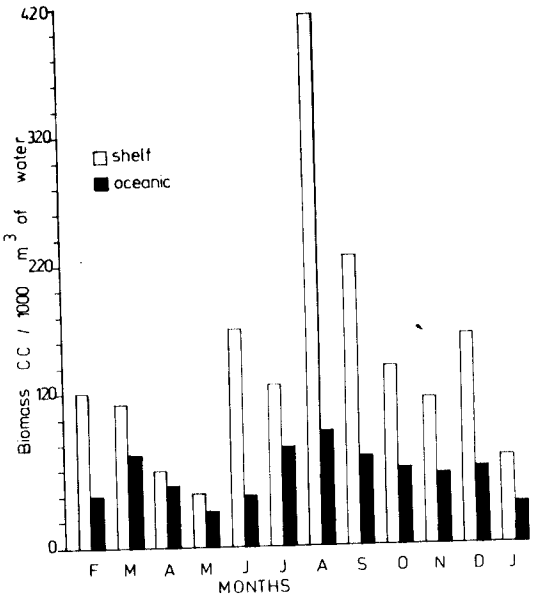

Fig. 5. Monthly abundance of zooplankton biomass in the shelf and oceanic waters of the area investigated.

region in the eastern Arabian Sea. The 2nd region in the Bay of Bengal with 36.9 cc was the least productive in the whole area investigated. The biomass value in this latitudinal region was equal to only 22% of the corresponding region off the west coast.

A much more detailed study was carried out for the zooplankton abundance during the three major seasons in the four latitudinal regions separately for the two major sea areas and the results are given in Fig. 7. Off the west coast while in regions 1 and 2 the maximum abundance was during the monsoon season, in the 3rd and 4th regions the same was during the premonsoon season. The sequence from maximum to minimum production in the former two regions was monsoon, postmonsoon and premonsoon, and off the east coast the sequence was premonsoon , monsoon and postmonsoon.

Another study carried out was the abundance in the shelf and oceanic areas off the two coasts separately during the three major seasons and the results are depicted in Fig. 8. It was found that each subsector presented different pattern of abundance seasonally.

Off the west coast in the first and second regions the sequence of abundance from high to low in both shelf and oceanic areas was monsoon,

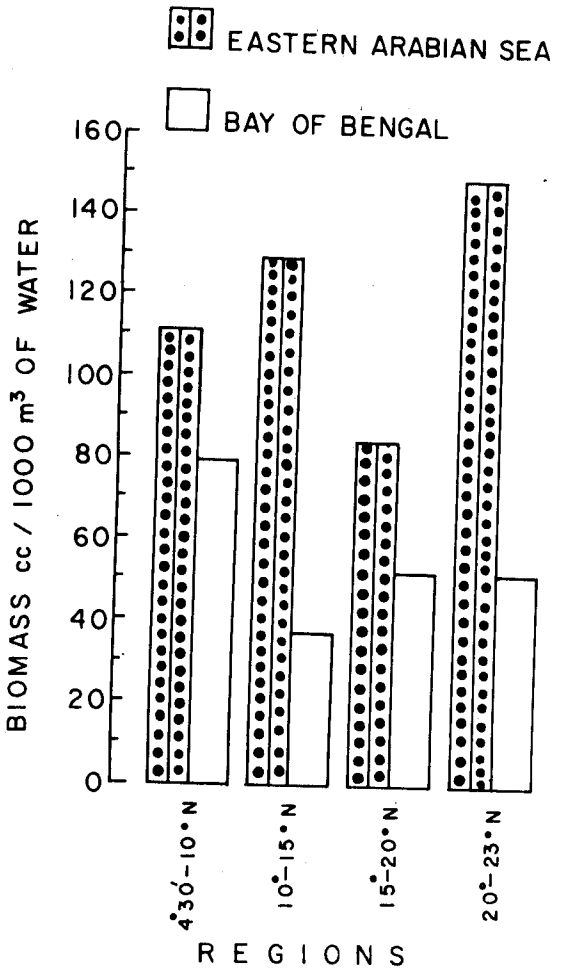

Fig. 6. Latitudinal abundance of zooplankton biomass in the eastern Arabian Sea and the Bay of Bengal

postmonsoon and premonsoon. In the 3rd region a different picture was obtained for the shelf area in the sense that there was no sequential increase or decrease through the three seasons. The maximum

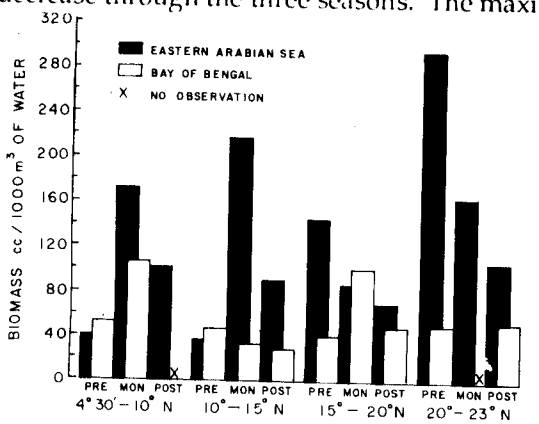

Fig. 7. Seasonal variations in the latitudinal abundance of zooplankton biomass in the eastern Arabian Sea and the Bay of Bengal.

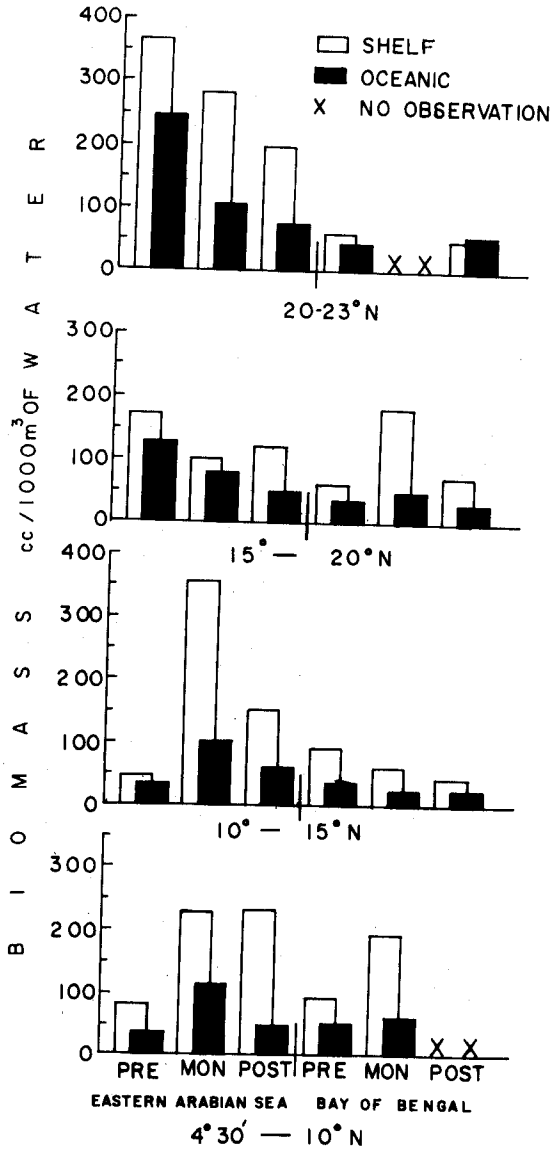

Fig. 8. Seasonal variations in the latitudinal abundance of zooplankton biomass in the shelf and oceanic waters of the eastern Arabian Sea and the Bay of Bengal.

biomass in the shelf area was observed during the premonsoon. During the monsoon season, a drastic reduction was seen only to make a marginal increase during the postmonsoon season. In the oceanic area of this region the maximum production was during the premonsoon period which amounted to about 50% of the total annual biomass. In the 4th region also the premonsoon production was the highest in the shelf and oceanic areas.

Off the east coast also the different areas did not present uniform pictures. Due to lack of data,

a comparison was not possible for the first and last latitudinal regions. In the second region, the sequence was premonsoon, monsoon and postmonsoon in both the shelf and oceanic areas. Same was the pattern observed in the oceanic waters of the thrid region. In the shelf area of this region monsoon yelded the maximum biomass followed by postmonsoon and premonsoon.

Day- night abundance

The total of 1,113 samples considered for the study were put under day or night categories and the results obtained are presented in Fig. 9. Almost in all months the night samples contianed more quantities of zooplankton. The maximum night abundance was in September and the percentage of increase was 79.07%. July accounted for an equal representation in day and night samples. During February and March the day samples contained slightly more zooplankton and the increase was by 12.81 and 5.98% respectively.

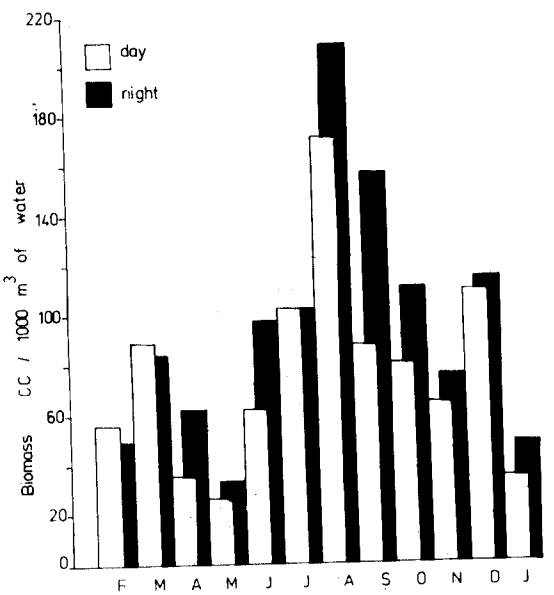

Fig.9. Monthly diurnal variations in the abundace of zooplankton biomass.

Estimated production at secondary and tertiary levels

Having examined the finer aspects of geographic distribution and seasonal, regional and diurnal abundance of the zooplankton in the study area, it was sought to understand the quantum of production at the secondary and teritary levels. The rate of secondary production for every half degree area was estimated following the method of Cushing (1973) which was subsequently revised by Dalal and Parulekar (1986). The vlaues obtained are plotted as grams carbon per m^2 / year in Fig. 10.

The average secondary production in every half degree square of the area under investigation ranged between 0.5 and 20. 92 $gC/m^2/year$. As expected, the west coast accounted for the maximum production. There, again, the shelf area was the most productive. The very high values of secondary production obtained from the northern Arabian Sea was mainly due to the abundant occurrence of the highly gelatinous macroplankton like salps, doliolids and medusae. In the Andaman and Nicobar waters, most of the values obtained were below 5 $gC/m^2/year$. Off the east coast most of the higher values obtained were towards the outlet of River Ganga. The far oceanic waters of the Bay of Bengal recorded relatively low secondary production.

From the values of secondary production, the fish production for the area under study and for the EEZ was worked out following the method of Cushing (1973) assuming that the tertiary production is equal to 10% of the secondary production. Accordingly, it was found that the entire area investigated accounts for a total fish production of 7.91 million tonnes. Out of this, the eastern Arabian Sea, Bay of Bengal and the Andaman and Nicobar waters have a share of 5.14, 1.38 and 1.39 million tonnes of fish respecitvely.

A separate estimate was made for the EEZ alone (Fig.11) and it was found that the EEZ of the west coast has a total fish stock of 4.78 million tonnes. The fish stock of the EEZ of the east coast and the Andaman and Nicobar seas worked out to be 1.32 and 1.37 million tonnes respectively. The fish production for the entire EEZ is estimated at 7.46 million tonnes.

If explotiation at 50% level of the total stock is envisaged, it could be seen that the Indian EEZ can yield upto 3.74 million tonnes of fish against the present yield of 1.6 million tonnes. Out of the potential yield, the share of the respective sea areas could be: west coast 2.39 mt, east coast 0.66 mt and Andaman and Nicobar seas 0.69 mt. If consdiered at the present level of explotiation, while an increase in exploiation by 100 % could be effected for the west coast, only 50 % increase may be contemplated

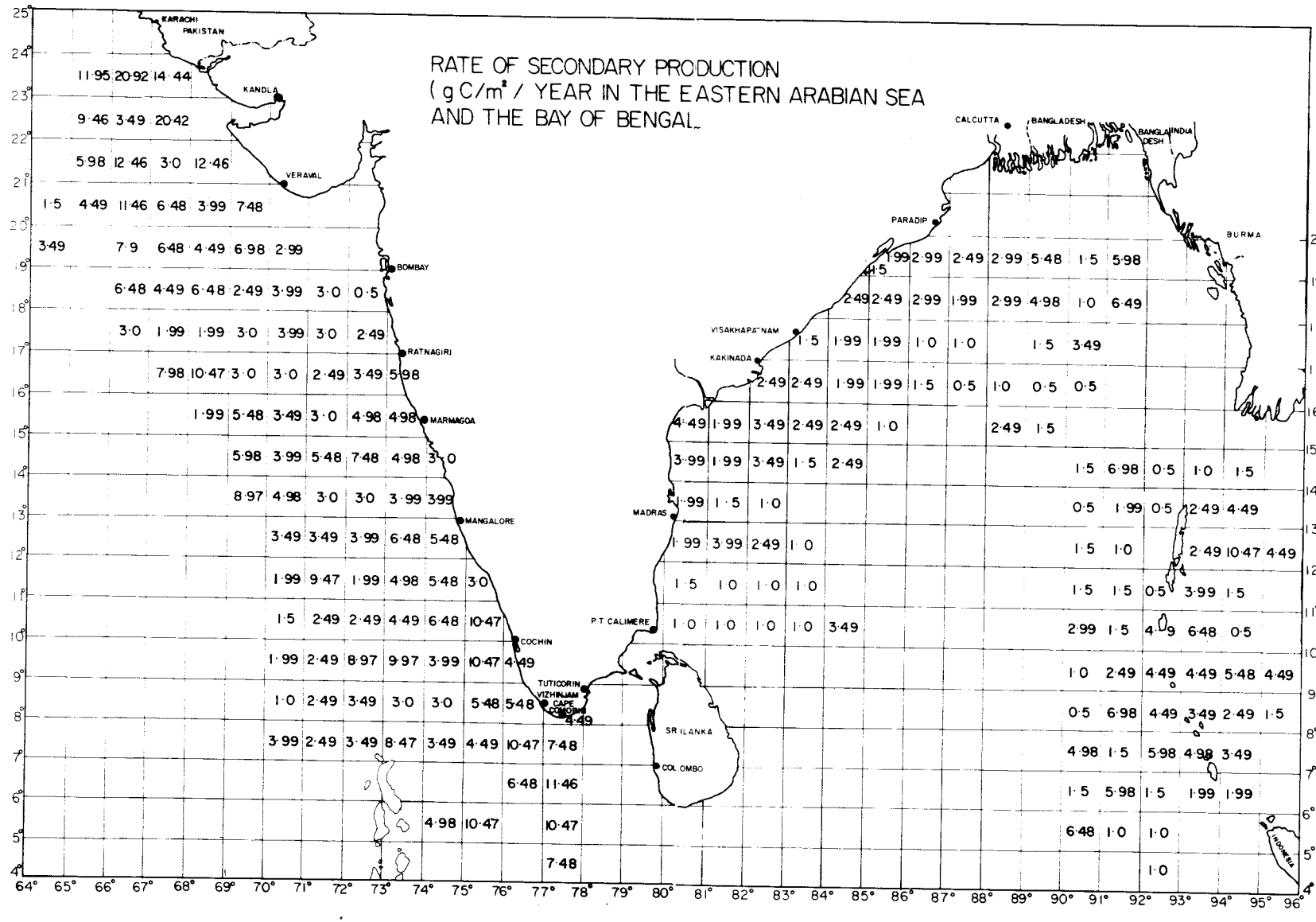

Fig. 10. Rate of secondary production in the EEZ of India.

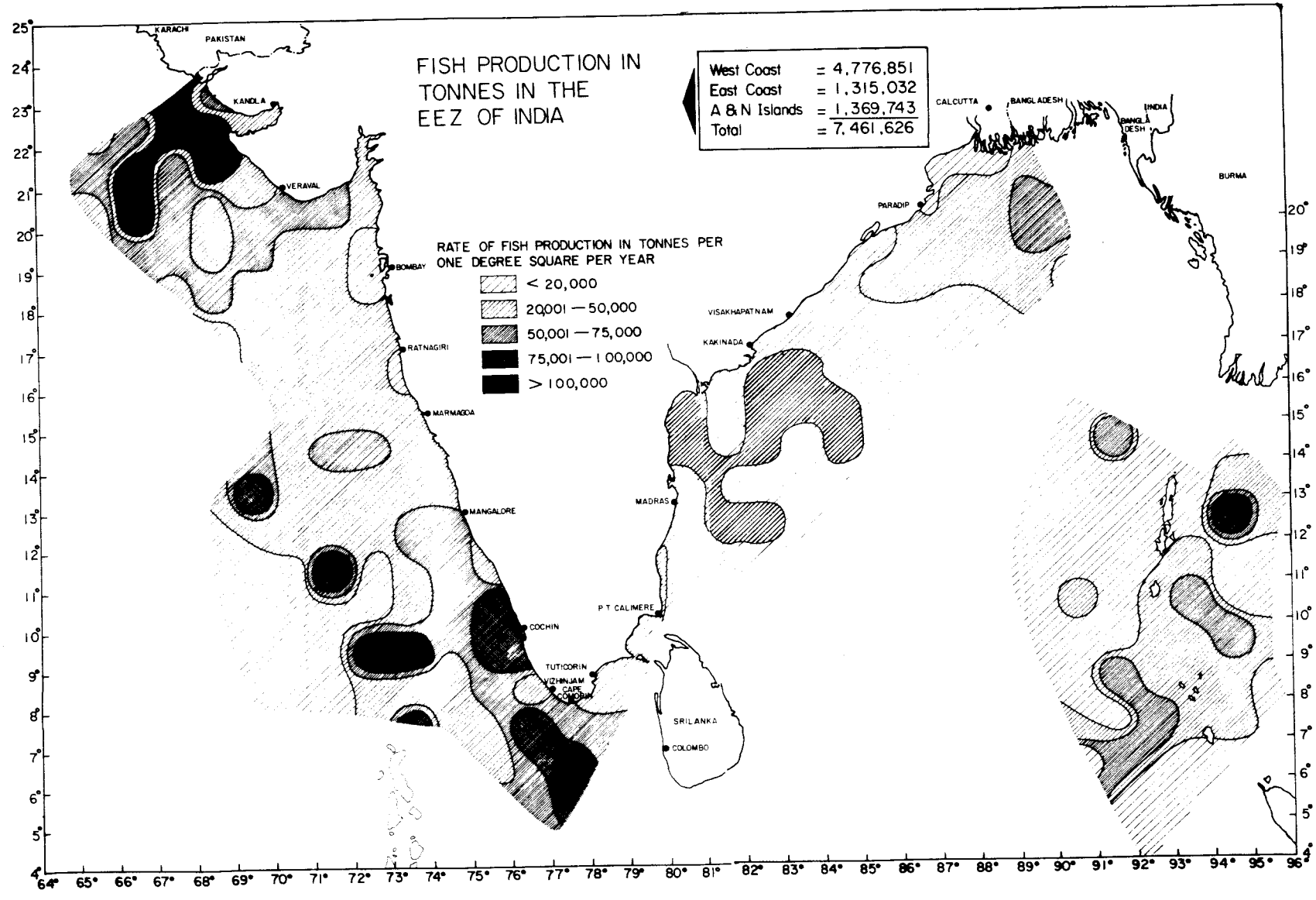

Fig. 11. Rate of fish production in the EEZ of India.

for the east coast. Since exact fish catch statistics are not available for the Andaman and Nicobar islands, the percentage of expected enhancemnt in fish catch cannot be visualised.

In this context it may be remembered that the coastal areas upto 50 m depth along both the coasts of India are being exploited intensively. Therefore any attempt in further exploitation may be planned beyond the 50 m depth zone. The FORV *Sagar Sampada* has located several rich grounds for both conventional and non-conventional fish resources on our EEZ beyond the presently exploited areas.

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